COMPARISON OF RESIDENTIAL BUILDING STANDARDS PROJECTS

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CALIFORNIA ENERGY COMMISSION

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1.0 EXECUTIVE SUMMARY

This report provides a comparison of the analyses conducted by NEOS for the Post-Occupancy Residential Survey project with the results and observations obtained from previous survey projects conducted for the California Energy Commission (Commission). Comparisons were made between all applicable cross-sections of the new data obtained from the 400 on-site surveys of single-family homes during this study and the data contained in two previous Commission reports. These previous two reports together comprise major elements of the "Residential Building Standards Monitoring Project" conducted over the period of 1988 through 1995. The two reports indicated are:

1. Occupancy Patterns & Energy Consumption in New California Houses (CEC Report P400-90-009, September 1990). This project entailed primary data collection by means of a nested sample of mail surveys (2,845), on-site surveys (299), on-site monitoring (40), and more detailed Short Term Energy Monitoring (STEM) tests (4). A second phase of this project was later added to carry out additional monitoring activities for more homes in order to expand the sample size for cooling load calculations. This project was carried out by means of a contract with the Berkeley Solar Group (BSG) and Xenergy, Inc. This report encompasses Phase One and Phase Two of the Residential Building Standards Monitoring Project, respectively, and are referred to as such in the remainder of this report.

2. Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses (CEC Report P400-91-031CN, May 1995). Under this project, also contracted with BSG, primary data collection activities were undertaken to obtain the CF-1R compliance forms for over 1,200 homes in Climate Zones 10, 12, 13, and 14. Additional on-site audits, metering, and duct leakage measurement activities were then conducted for a sample of approximately 100 homes. This report comprises Phase Three of the Residential Building Standards Monitoring Project, and is also referred to in this manner throughout the remainder of this report.

The data and information contained in these two reports were compared with the on-site data and building simulation results obtained from this project. The objective of these comparisons was to show trends in building construction practices, construction component and equipment efficiencies, as well as in compliance rates with building standards over time.

1.1 Background

The California Legislature passed the Warren-Alquist Act in 1976, which created the Commission and directed it, among other things, to develop Energy Efficiency Standards (Standards) for new buildings. Such Standards were to be periodically updated to be cost effective with respect to historic and current practice. The Commission issued the first energy efficiency standards in 1978 and has revised and updated them regularly since that time.

Field research information is considered an essential component of the review process for the Standards, which occurs under the Public Resources Code (PRC), Section 2540Z. In fiscal year 1995-96, the Commission solicited proposals for several contracts which were to help evaluate:

- Whether the Standards are based on realistic assumptions;
- Whether the expected energy savings are being realized; and
- How selected elements of the program could be more effective.

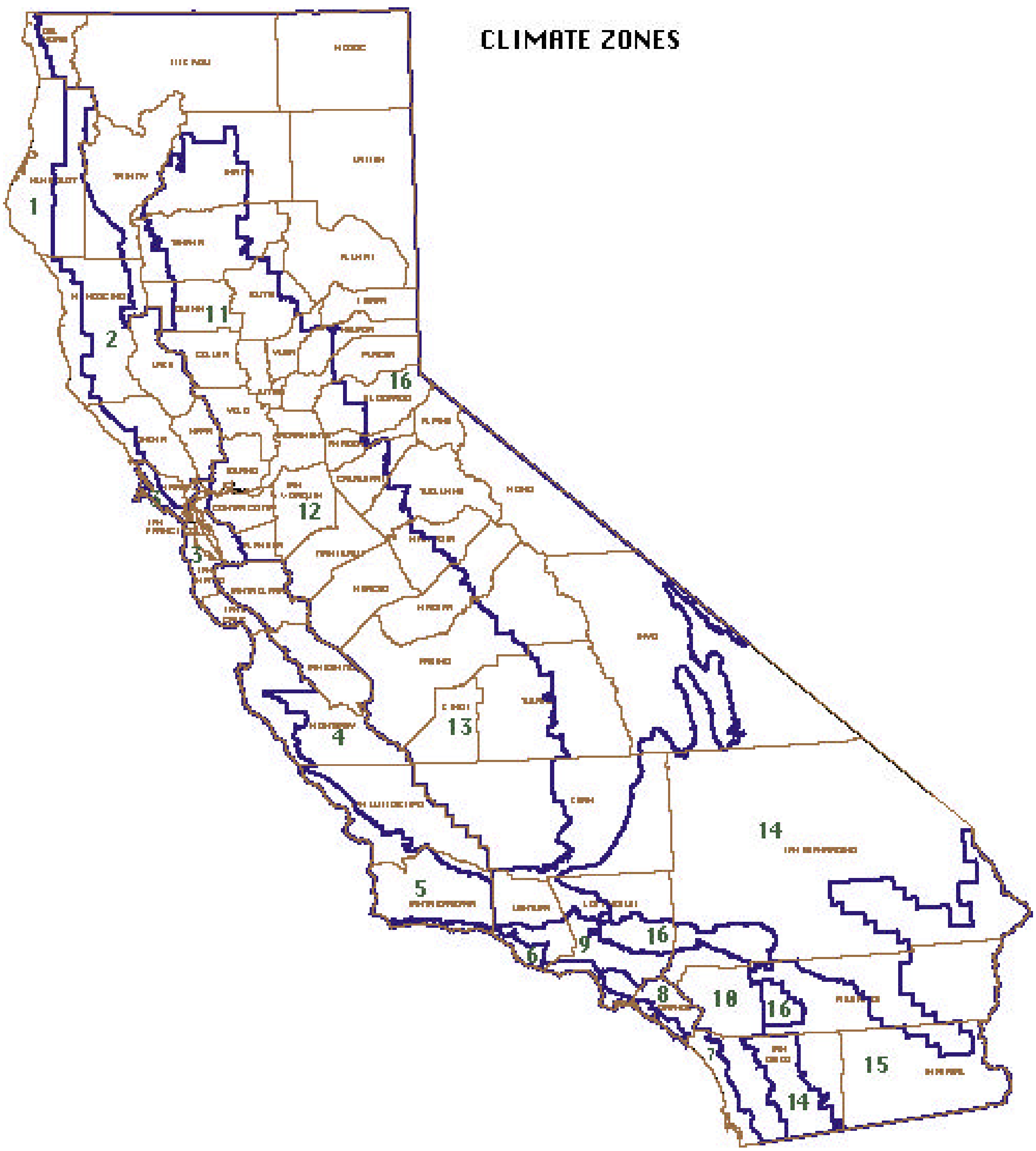
The Post Occupancy Residential Survey project conducted by NEOS is one of the contracts designed to provide information to the Commission necessary to satisfy these objectives. This project was designed to collect data from 400 single-family detached houses constructed since July 1, 1989, distributed across all 16 California climate zones. Figure 1-1 shows the climate zone boundaries utilized by the Commission for the Standards in relation to State County lines. While incremental changes in climate zone boundaries have occurred over time, they have remained essentially the same since the inception of the Standards in 1978, and are consistent over the course of all three projects included in this report.

The primary objectives of the Post Occupancy Residential Survey project were to examine:

1. If and how the surveyed houses initially complied with Title 24 Standards;
2. If energy efficiency measures were removed after homeowner occupancy;
3. If additional energy efficiency measures were installed after homeowner occupancy;
4. Why energy efficiency or energy saving measures were removed or installed by homeowners;
5. How the results of these 400 surveys compare with the two previous Commission surveys.

This report specifically addresses the last of these objectives in detail. The remainder of this section provides a brief qualitative overview of the comparison results. Section 2 provides a description of all three projects and lays the foundation for the quantitative comparisons of the data and analyses contained in Section 3. Section 4 presents the results of the CALRES simulations across all comparable segments of the data between the projects. Section 5 provides the summary and conclusions from the comparison exercise.

Figure 1-1
California Climate Zone Boundaries



1.2 Overall Comparisons

Data regarding building energy efficiency characteristics were compared between the three projects for four building components: structure, HVAC equipment, hot water equipment, and appliances. In general, variations between the energy efficiency characteristics of the homes in the three surveys were strongly correlated with the vintage of the home and the Standards in effect at the time.

The houses surveyed in Phases One and Two of the Residential Building Standards Monitoring Project were built in the years 1984 through 1988. The houses surveyed in Phase Three of the project were built primarily in 1993, with some houses built in 1994. Houses surveyed for the Post Occupancy Residential Survey Project were built in the years 1989 to 1995, with most of the homes built in 1990 through 1993. Consequently, data from the Phase Three survey and the current project represent approximately the same time frame, while the Phase One survey data represent homes built under prior energy standards and building practices.

For building structure, there appeared to be little difference among the houses from the three projects in terms of number of floors, average floor area, floor type, window area per floor area, and average window area per household. However, houses in the NEOS project appear to have higher levels of roof, wall, and floor insulation as well as more efficient window glazing. This is expected since the more recent energy standards require higher levels of insulation and more efficient window glazing.

With regard to HVAC equipment, there appeared to be little difference between the houses participating in the NEOS project and the houses that participated in the 1993 project. Differences are evident in HVAC system efficiency between the Phase One and Two homes and both the Phase Three and the current project. In the latter projects, the cooling equipment SEER and heating equipment AFUEs are higher, which matches the stricter requirements of the newer Standards.

For hot water equipment, comparisons between the projects were made by examining the water heater efficiencies and the water heater fuel types. However, these comparisons could only be made between the current project and the 1990 report for Phase One and Two. Data for these variables were not available from the Phase Three report. Comparisons between the current project and the 1990 project results indicate that the water heater equipment installed in the homes was very similar . The water heater efficiencies were nearly identical in both projects, and natural gas was the predominant water heater fuel type.

For other general appliances in the home, comparisons between the projects were made by looking at the presence, and in some cases the fuel type, of clothes washers and dryers, cooking equipment, freezers, and hot tubs/spas. Except for the cooking fuel type, comparable data were only available between the current project and the Phase One and Two 1990 project. The presence of freezers was lower in the current project when compared to the earlier data. Natural gas is more common as the fuel type of choice for clothes drying and cooking in the current data than in the two previous projects. The presence of hot tubs/spas appears to be lower in the current project compared to the Phase One and Two project.

More detailed quantitative comparisons of these aspects of the data between the projects is provided in Section 3.

1.3 Summary Of Calculated Energy Performance

Although the CALRES building energy simulation computer program was used in all three projects, insufficient detail was provided in the Phase One and Two data to permit a valid comparison of the results with the other projects. Comparisons were, therefore, limited to the cross-section of applicable climate zones between the Phase Three data and the current Post Occupancy data. The majority of the houses (89 percent) surveyed in the Post Occupancy Residential Survey were built while the 1988 Title 24 energy codes were in effect. The Phase Three homes, however, were modeled using the 1992 Title 24 energy codes. The use of these two vintages of energy codes provides a historic comparison between the two generations of energy codes. For the Post Occupancy survey data, the pre-occupancy compliance data were used, since that is how the homes were shown to comply with the Title 24 energy codes.

A comparison of the levels of compliance for the two projects indicated is presented in Table 1-1. While the levels of compliance are not identical between these two projects, the comparisons do show consistency by climate zone. Both projects showed that the lowest levels of compliance occurred in Climate Zone 14 and the highest levels of compliance occurred in Climate Zone 10. These results also indicate a relatively low compliance rate in Climate Zone 12.

Table 1-1 Performance Compliance of As Built Audited Houses (1993 and 1996 On-Site Survey Projects)

	1996 On-Site (1988 Codes)		1993 On-Site (1992 Codes)	
Climate Zone	**# of Homes**	**% Complying**	**# of Homes**	**% Complying**
10	44	39%	26	69%
12	92	26%	24	29%
13	25	48%	22	50%
14	15	7%	24	8%
Total	176	31%	96	40%

Table 1-2 presents a comparison of the percentage margin in the compliance rates between the comparable data from the two projects indicated. The percent margin is defined as the amount over (negative) or under (positive) the required compliance rate that the average for each climate zone represents. Therefore, a margin of positive percentage indicates that the average compliance rate for the region is better than the required value.

As this table shows, the margins between three of the climate zones are within four percentage points of each other, and can be considered quite comparable between the two projects. The exception is Climate Zone 14, which showed similar trends between the projects, but with a much greater magnitude of difference. Differences in the sample size, house size, window area to floor area ratios, as well as heating and cooling equipment efficiencies are all factors which can effect the results of the energy simulations between the two projects.

Table 1-2 Average Energy Performance of As Built Audited Houses (1993 and 1996 On-Site Survey Projects)

Climate	1996 On-Site (1988 Codes)		1993 On-Site (1992 Codes)	
Zone	Total	% Margin	Total	% Margin
10	44	-1%	26	3%
12	92	-6%	24	-6%
13	25	-3%	22	-1%
14	15	-16%	24	-8%

2.0 PROJECT DESCRIPTIONS AND MAJOR FINDINGS

This section serves to document the approach and major findings from each of the three projects included in the comparisons on an individual basis. The background and purpose of each project is explained, along with the means of data acquisition, analysis techniques, followed by a summary of the important results and conclusions from each of the projects. Section 3 of this report provides a side-by-side comparison of the data between all three projects.

It is worth noting again that the two reports against which this Post Occupancy Residential Survey was compared collectively comprise the Residential Building Standards Monitoring Project. The first report includes two phases of analysis, defined as Phase One and Phase Two, while the second report comprises Phase Three of the Building Standards Monitoring project. The descriptions included in this section refer to the various projects by Phase, in keeping with established nomenclature used at the Commission. Much of the background information and discussions presented below for all three of phases of the previous efforts are excerpted from the two reports referenced earlier.

2.1 Phase One Of The Residential Building Standards Monitoring Project

Assembly Bill 191 (Bradley), enacted in 1987, required the California Energy Commission to conducted a pilot project of field testing of residential buildings to:

1. assess the accuracy of the (California Title 24 Energy Efficiency Standards) modeling assumptions and recommend revisions where appropriate, and

2. evaluate the impact of the Standards on energy use, cost-effectiveness, and indoor air quality.

In response to AB191, the Commission conducted the Residential Building Standards Monitoring Project through a contract with the Berkeley Solar Group (BSG) and Xenergy, Inc. In addition, the following utilities participated in the project:

1. The City of Riverside
2. Los Angeles Department of Water and Power
3. Pacific Gas and Electric Company
4. San Diego Gas and Electric Company
5. Southern California Edison Company
6. Southern California Gas Company

The project was limited to single family homes built between 1984 and 1988, and was conducted in three major steps: data acquisition, data analysis, and data synthesis and recommendations.

2.1.1 Data Acquisition

The research team for Phase One acquired data from four separate activities:

1. Xenergy conducted a mail survey of a stratified random sample of 7,477 new single family house occupants throughout California; 2,845 completed surveys were received. The survey solicited data on over 150 variables, including the physical characteristics of the homes, the hours of occupancy, thermostat setpoints and schedules, the appliances in use, the number and age of the household's occupants, and family income.

2. The research team conducted on-site surveys of a stratified random sample of 299 houses from the mail survey sample. These surveys produced detailed measurements of the physical characteristics and energy-utilization systems of the houses.

3. BSG conducted on-site monitoring of 40 houses from the mail survey sample. Data loggers were installed in each house to measure the operation of the heating, cooling, and domestic water heating systems and the indoor and outdoor temperatures for a five week period. Blower door tests and perfluorocarbon tracer tests were used to measure the air tightness and air change rates in each house.

4. BSG and the Solar Energy Research Institute (SERI) conducted Short Term Energy Monitoring (STEM) tests of four unoccupied houses. Each STEM test consisted of a 4 day procedure of highly accurate measurements of weather conditions, indoor air temperatures, and applied and natural energy flows in the home.

2.1.2 Data Analysis

The data acquired from Phase One were analyzed as follows:

1. Xenergy conducted a Conditional Demand Analysis (CDA) of the energy consumption of approximately 2,000 of the 2,845 households which responded to the mail survey, determining statistical estimates of energy consumption for space heating, space cooling, domestic water heating, and the other major energy end uses in all new California houses.

2. Xenergy conducted a Princeton Scorekeeping Method (PRISM) analysis of the energy consumption of a portion of the 299 households which were the subject of on-site surveys, determining the actual energy consumption for space heating, space cooling, domestic water heating, and the other major energy end uses in each of the households.

3. BSG performed CALRES simulations of the energy consumption of 218 of the households which were the subject of both the on-site surveys and the PRISM analysis.

2.1.3 Data Synthesis

BSG calibrated the modeling assumptions by comparing the assumed characteristics of new California houses with their actual characteristics (as determined in the data acquisition and analysis portions) and proposed four sets of revised modeling assumptions to better match actual conditions. BSG then performed five CALRES simulations of each of the 218 houses, one based on the existing modeling assumptions and four based on the proposed modeling assumptions, to determine what set of modeling assumptions best described actual conditions and enabled the computer model to most accurately predict energy consumption. (The modeling assumptions are used by the Commission in developing and updating the Standards, and they are used by building designers in demonstrating compliance with the Standards.)

In general, BSG found that CALRES simulations based on the existing modeling assumptions tend to overestimate heating energy consumption by approximately 20 percent and overestimate cooling energy consumption by approximately 50 percent.

BSG evaluated the impact of the Standards on energy use and cost-effectiveness by comparing the actual energy consumption and life-cycle cost of each of the 218 houses with what the energy consumption and life-cycle cost would have been if the Standards had not been in effect. BSG accomplished this by identifying the energy conservation measures which were required by the Standards and performing two CALRES simulations of each house, one with and one without the measures included.

BSG investigated the impact of Standards on indoor air quality by deriving data from the on-site monitoring of infiltration of outside air and comparing these data and other physical characteristics of the houses to a national standard for ventilation (ASHRAE 62-1989); in addition, Xenergy solicited subjective evaluations of indoor air quality from the respondents to the mail survey.

2.1.4 Findings From Phase One

BSG recommended that several of the computer modeling assumptions be revised to better match conditions in real California houses and permit computer models to more accurately predict energy consumption. Among these revisions are the following:

1. Change the single family base case house (on the basis of which the Commission develops the Standards) to a single-story, slab-on-grade house of 1,900 square feet floor area, with 285 square feet of windows, single glazed in the South Coast region and double glazed elsewhere, with a shading coefficient of 0.57 when the shades are closed, and with 70 percent of the area of the ceiling under an attic.

2. Reduce the solar gain through windows by 50 percent from current assumptions and reduce infiltration to approximately 0.35 air changes per hour, modeled according to the ASHRAE ELA procedure.

3. Increase the heating thermostat setpoint from 68 degrees F to 70 degrees F (66 degrees F at night), but assume that heating and cooling systems operate only about 50 percent of the time. Maintain the internal heat gain. Increase the domestic water heating energy consumption. Vary both internal heat gain and domestic water heating energy consumption with season (higher in the winter and lower in the summer). Reduce the voluntary ventilation rate (windows opened by occupants).

BSG found that the Standards in effect at the time the sample houses were built reduced energy consumption substantially, saving California households an average of $762 per year. The Standards were found to be overwhelmingly cost-effective, saving households an average of $18,000 (discounted net present value) over the life of the conservation measures. The life-cycle cost savings were found to be an average of nine times the installation costs of the conservation measures. In other words, California households derive, on balance, substantial benefits from complying with the Standards. The obvious conclusion to which this finding leads is that the legislature acted wisely to direct the Commission to develop the Standards and that the Commission delivers a significant service to the people of California in continuing to update and support the Standards.

The research project found no evidence that the Standards have affected indoor air quality. It is a matter of concern, however, that the total air change rate in one third of the houses monitored was less than the minimum rate recommended by the selected national reference standard, although all of the houses met the standard by virtue of the fact that they had operable windows. It was found that the occupants of new California houses overwhelmingly (by thirty to one) consider the indoor air quality in their new houses to be equal or superior to that in their previous houses. Substantial additional research in this area is needed to identify the major sources of indoor air pollution, the effects they have on people, and the appropriate public policy on this matter.

2.2 Phase Two Of The Residential Building Standards Monitoring Project

Phase Two of the project extended the data collection and analysis activity of Phase One to expand the data set supporting the modeling assumptions regarding cooling. Phase Two comprised three tasks:

2.2.1 Expanded Monitoring of Cooling System Behavior

The monitoring activity in Phase One was based on a random sample of 40 houses selected from the 2,845 houses surveyed by mail. Of these houses, however, only 11 were equipped with cooling systems, and the 11 were spread over four climate zones; this yielded too small a sample of cooled houses to support reliable conclusions. In this task, BSG collected data on cooling system operation in 33 houses, all equipped with air conditioning systems, and all located in a single climate zone, to improve the isolation of cooling energy consumption from other end uses in the house's overall energy consumption.

2.2.2 PRISM Analysis Of Data Collected

The PRISM analysis of 150 houses included in Phase One yielded some apparently unreliable results, including negative estimates of cooling energy consumption and substantial differences between the results of the PRISM and Conditional Demand Analysis. In this task, Xenergy improved the analysis of the billing data by using various techniques, including the following:

1. Xenergy expanded the PRISM analysis to include all the houses for which data were collected in Phase One.

2. Xenergy enhanced the PRISM algorithms to incorporate a seasonally variable estimate of base (non-cooling) electricity consumption, to take into account seasonal variations in energy consumption for lighting (because of shorter daylight hours), cooking, and television usage.

3. Using the results of the enhanced PRISM calculations, Xenergy performed an analysis of variance in cooling energy consumption to identify the magnitude of variation and the non-climatic factors which influence cooling energy consumption.

2.2.3 Non-Response Analysis

Xenergy performed a statistical analysis to determine how well the energy consumption by the respondents to the survey represented that of typical residents in a new house. This was accomplished by comparing utility bills between respondent and non-respondents to the mail survey.

2.2.4 Findings From Phase Two

The major findings from Phase Two of the project include the following:

1. **Monitored Of Occupant Cooling System Operation.** Occupants of new California houses with air conditioning in the Central Valley region behaved significantly differently than was assumed by the standard Commission modeling assumptions. The Commission assumed that occupants always air conditioned their houses to maintain a setpoint of 78 degrees F. The research results indicated that when they air conditioned, occupants maintained an average set point of approximately 80 degrees F. In addition, most occupants air conditioned their houses only part of the time. The average occupant maintained his or her own cooling thermostat setpoint only 63 percent of the time during the critical afternoon period. The combination of these two factors meant that the standard assumptions overestimated the energy consumption for cooling and the energy savings from cooling conservation measures in a typical new house.

   In order to improve the match between the Commission energy calculations and the actual energy bills and measures behavior in typical new houses, BSG recommended that the occupant behavior assumption be changed to provide for a cooling thermostat setpoint of 80 degrees F. In addition, BSG recommended that the schedule be changed to provide for the cooling system being off during a significant fraction of the daytime hours. In making revised schedule assumptions, BSG recommended that the Commission take into account internal gains that were related to occupancy (such as heat gain from people and cooking) and those which were independent of occupancy (such as heat gain from refrigerators). BSG also recommended that the assumptions be set to represent the occupant behavior expected over the life of the house. BSG recommended that the Commission investigate existing utility data sets to determine whether there is a relationship between cooling energy use and family size, age or other demographic factors.

2. **PRISM Analysis of Central Air Conditioning UEC's.** The PRISM monthly billing data analysis technique yielded significantly more accurate cooling energy results by including a term which accounted for seasonal non-cooling electricity use. An analysis using the improved technique of an expanded sample of 764 new houses with air conditioning yielded estimated average cooling energy use 17 percent higher than the previous analysis. The analysis of the expanded sample included houses in the desert region previously excluded from the study. Using the improved technique and including the desert region yielded an estimate of average new house cooling energy consumption of 2,633 kWh per year. BSG recommended that the Commission use the improved PRISM model in future analysis work.

3. **Factors Correlated With Cooling Energy Consumption.** Phase Two analysis of the survey data collected in Phase One identified four factors which were correlated with the variation in cooling energy consumption of the individual houses in the expanded sample of 764 houses (in order of significance):

- Occupants who reported that they were in the house and operating their cooling system during the daytime on weekdays used 623 kWh more than the average.
- Occupants who reported that they rarely used their air conditioning system used 847 kWh less than the average.
- Occupants who reported higher annual household income used more cooling energy, at a rate of 6.6 kWh per $1,000.
- Larger houses used more cooling, at a rate of 0.74 kWh per square foot.

Four additional factors, the number of stories, occupant reported site shading, occupant use of drapes, and occupant use of other shading devices were not found to be significantly correlated with cooling energy use.

4. **Potential Non-response Bias.** Analysis of the utility bills of all 4,694 house occupants in the Phase One sample from the PG&E service territory found that there was a significant non-response bias in that occupants who used less than 10 kWh per day were less likely to respond than those who used more than 10 kWh per day. The average electricity use of respondents was 7 percent higher than the average electricity use of the original sample. This bias tended to make the average energy consumption estimates produced in the project slightly higher than the actual average of the population. High energy use behavior and lifestyle characteristics would be somewhat overstated compared to their actual occurrence in the population.

2.3 Phase Three Of The Residential Building Standards Monitoring Project

Berkeley Solar Group and its project team carried out the 1993 Residential Field Data project for the Commission and the California DSM Measurement Advisory Committee (CADMAC). The primary purpose of the project was to determine the conservation and occupancy characteristics of new single family houses built in hot valley climates which comply with the Energy Efficiency Standards for New Low Rise Residential Buildings and which do not participate in utility sponsored conservation programs. As part of this effort, BSG and the project team carried out the following major tasks:

1. BSG obtained Compliance Forms 1R (CF-1R), which were submitted to local building departments for single family houses completed during specific time periods in 1993 and 1994 in Climate Zones 10, 12, 13, and 14. The California Energy Standards require that builders submit CF-1R for each new house built. The CF-1R describes the new energy efficiency features and shows how the house complies with the Standards. BSG worked with the CADMAC utilities to screen out CF-1Rs for houses which were participants in utility new construction conservation incentive programs. BSG entered data from the remaining 1,230 CF-1Rs into a database and analyzed the information to determine the self-reported energy efficiency measures and

characteristics of new houses meeting California Energy Standards.

2. BSG recruited one hundred occupants of the new houses to participate in an on-site audit and monitoring study. BSG measured and inspected each audited house to determine independently its characteristics and conservation measures. BSG then compared the measured characteristics of the audited houses to the characteristics reported by their builders on the CF-1Rs, which had been supplied by the building departments.

3. BSG measured heating and cooling system operation and thermostat setpoints at each audited house for a period of one month. BSG analyzed this data to determine the fraction of the time that occupants conditioned their houses and the setpoint they maintained during the air conditioning and heating operation.

4. BSG performed an independent compliance analysis using the Commission performance approach for each house to determine whether, as built, it complied with the 1992 California Standards.

5. BSG performed two additional independent compliance analyses using alternative analysis rules and assumptions. The first alternative analysis used current default glazing U-factors instead of the more lenient temporary defaults in effect in the six months of 1993. The second alternative analysis added the effect of site shading and the measured thermostat schedules for both the proposed and standard designs.

6. BSG tested a new simplified duct leakage measurement protocol in the audited houses and compared it to blower door and duct-blaster measurements in a subset of 20 houses. Based on this analysis, BSG prepared recommendations for new duct efficiency provisions for the 1996 Standards revision.

7. BSG also carried out a series of nine Short Term Energy Monitoring experiments at six other new houses in climate zones 10 and 14.

2.3.1 Findings From Phase Three

The major findings from Phase Three of the project include the following:

1. The CF-1R forms provided self-reported data that was analyzed to provide various energy efficiency characteristics. These items included information on the size of the houses (an average of 1,876 sq. ft.), the type of floor (92 percent slab on grade), and glazing area as a percentage of conditioned floor area (average of 14.8 percent to 19.4 percent depending on the climate zone). Data on windows were also collected which led to the observation that the majority of windows were double-glazed (92 percent), had metal frames (90 percent), and used the Commission default

interior shading (82 percent).

2. Comparison of the data gathered in the field audits with the data in the CF-1Rs submitted by the builders of the audited houses revealed many serious discrepancies. Sixty-six of the 96 audited houses overstated the efficiency of one or more of the five important measures, which were significantly different from those reported in the CF-1Rs. All of the 96 audited houses overstated the efficiency of at least one measure, thereby failing to comply with the administrative requirements of the Standards.

3. For the Mandatory Measures, or those measures which the energy efficiency standards require in all new houses, and which are not allowed to be traded off in calculations, BSG found significant non-compliance in only two areas. Hot water pipes are required by the Standards to be insulated for the first five feet or until they pass through a conditioned wall. This insulation was found to be missing in 20 houses. High efficiency fluorescent lights are required by the Standards in all kitchens and bathrooms, with its switch at the entrance of the room. This condition was found to be missing in almost half the houses.

4. BSG monitored heating and cooling activity in each audited house for a period of one month. BSG then analyzed the data in order to infer the hourly thermostat setpoints and the fraction of time during which the houses were conditioned. Setpoint assumptions were an important factor in the Commission performance analysis rules because they determined the balance of cooling and heating consumption for each house and thereby ultimately determined the tradeoffs between cooling and heating oriented efficiency measures. The Commission assumptions of daytime heating and cooling setpoints were close to the measured values. However, the measured data did not support the Commission assumption of a large nighttime setback of the heating thermostat setpoint. In addition, the measured data did not support the Commission assumption of one hundred percent continuous air conditioning. The measured data showed that occupants condition their houses approximately 60 percent of the time during peak occupancy periods.

5. BSG prepared three sets of independent CALRES analyses of energy consumption based on the measured characteristics of the audited houses. The first set of analyses followed the standard Commission rules for compliance calculations in effect at the beginning of 1993. Using these standards, half of the audited houses complied with the performance path of the Standards. The second set of analyses used glazing U-factor default tables in effect as of July 1993. These stricter standards caused eleven homes which previously complied under the January 1993 requirements to fail the performance compliance standard. Finally, the third set of analyses added the effect of site shading from adjacent houses and revised thermostat settings to the houses simulated in the second round. With this approach, the compliance rate did not change, but total energy consumption was reduced by 17 percent.

2.4 Post Occupancy Residential Survey Project

This project involved the collection of data from 400 single-family detached houses constructed since July 1, 1989, distributed across all 16 California climate zones. The five primary purposes of this effort were to examine:

1. If, and how, the surveyed houses initially complied with Title 24 Standards;
2. If energy efficiency measures were removed after homeowner occupancy;
3. If additional energy efficiency measures were installed after homeowner occupancy;
4. Why energy efficiency or energy saving measures were removed or installed by homeowners;
5. How the results of these 400 surveys compare with the two previous Commission surveys.

2.4.1 Sample Size And Weights

In previous projects, such as the Residential Building Standards Monitoring Project, the distribution of the houses to be surveyed or monitored was based on issues other than building activity and climate zone distribution. For this project, great care was taken to provide a wide distribution of sample points across the State. Areas of high building activity were given the highest emphasis, while inclusion of houses in the less active building construction or populous areas was also mandated by the project specifications. The final project sample size, distribution, and weights are presented in Table 2-1.

Proportional allocation was used to determine the sample size for most strata with a minimum of 15 sample points imposed to ensure sufficient precision for the zones with the least construction activity. These results can be weighted by the ratio of climate zone to statewide building activity in order to achieve statistically valid results for estimates at the statewide level. Statewide estimates have a precision level of 95 percent degrees of confidence and a 5 percent margin of error.

It should be noted that the comparison of the results from this study with those of the previous projects was not possible for all climate zones. As indicated, the previous studies concentrated their data collection activities in specific climate zones related to the specific research objectives sought from each effort. By the same reasoning, statewide comparisons of the results from this project with the other studies are not possible, since no equivalent statewide samples are obtainable from them.

Table 2-1 Final Project Sample Size, Distribution, And Weights

Climate Zone	Estimated Building Activity N_h	Sample n	Largest City in Climate Zone	Precision Level % Confidence/ % Margin of Error	Weight w
1	4,066	15	Eureka	80/17.5	271
2	19,637	15	Santa Rosa	80/17.5	1,309
3	24,552	18	Oakland	80/15	1,364
4	15,033	15	San Jose	80/17.5	1,002
5	6,049	15	San Luis Obispo	80/17.5	403
6	19,591	15	Long Beach	80/17.5	1,306
7	24,191	18	San Diego	80/15	1,344
8	23,708	18	Santa Ana	80/15	1,317
9	19,623	15	Los Angeles	80/17.5	1,308
10	69,813	52	San Bernardino	80/10	1,343
11	32,433	25	Roseville	80/12.75	1,297
12	105,139	99	Sacramento	95/10	1,062
13	59,045	35	Fresno	80/11	1,687
14	37,654	15	Hesperia	80/17.5	2,510
15	14,589	15	Palm Springs	80/17.5	973
16	12,765	15	South Lake Tahoe	80/17.5	851
Total For State	487,888	400		95/5	1,220

2.4.2 Collected Survey Data

There primary aspects of data collection were emphasized during this project. These included:

1. Collecting basic homeowner occupancy, as well as information on the age and quantity of various appliances and energy using equipment;
2. Gathering all data necessary to conduct CALRES simulations for each house. This included all of the information available on the construction and equipment characteristics of the house, such as window areas, wall areas, ceiling and floor information, heating and cooling equipment, and hot water equipment information; and
3. Obtaining data on changes to the home made by the homeowner after occupying the house. This included the addition, removal, and replacement of energy efficiency measures or items which effect energy use in the house.

All of this information was documented using survey forms designed specifically for this project. In addition, a Microsoft FoxPro® database was designed to match the on-site data collection forms and used to carry out all data entry and management activities throughout the course of the project.

2.4.3 Non-Response Bias Survey

To assess the validity of the data collected for this project, 26 former non-respondent homes in Climate Zone 12 were recruited by the Commission. These 26 homes were part of the original sample, but chose not to participate in the on-site survey. The results of the data collection of these 26 homes were analyzed in conjunction with the other homes surveyed in Climate Zone 12. This analysis was designed to answer questions relating to possible non-response bias in the sampling and recruitment procedures for the project. The Commission became concerned that the homeowners participating in the survey might be homeowners who were more interested in energy efficiency. For this reason, Commission staff conducted the recruitment effort of homeowners previously recruited but who did not choose to participate in the survey. The analysis concluded that the non-response bias may make the standard budget estimates derived from the Post-Occupancy Residential Survey lower than the actual average of the population.

2.4.4 CALRES Simulations

The project database was used to conduct two CALRES energy simulations for each house in the survey. The first simulation was for the pre-occupancy case. This simulation removed or added the energy efficiency items the homeowner had added or removed since occupancy. The second simulation was for the post-occupancy case, which was the as-surveyed case. Energy efficiency items that were added or removed by the homeowner were included in this simulation case. Results of the CALRES model runs were tabulated and provided to the Commission, along with the CALRES input files.

2.4.5 Findings From The Post Occupancy Residential Survey Project

Title 24 Compliance

The CALRES Energy Simulation Program was used to determine compliance with the Title 24 Energy Standards. Based on these energy simulations, 38 percent of the houses complied with Title 24 before homeowner occupancy. The level of compliance varied greatly from climate zone to climate zone, so the compliance rate of 38 percent is deceptive because nearly one-quarter of the houses were located in Climate Zone 12, which had a low rate of compliance. Several climate zones (2, 4, 6, 7, 11, and 16) had compliance rates of over 50 percent. One climate zone, Climate Zone 1, actually had no houses which complied with the Title 24 Energy Standards. A breakdown of the compliance levels for each climate zone is presented in Table 2-2.

Table 2-2 Performance Compliance of As Built Audited Houses

Climate Zone	Comply	Don't Comply	Total	% Complying
1	0	15	15	0%
2	8	7	15	53%
3	4	14	18	22%
4	10	5	15	67%
5	1	14	15	7%
6	11	4	15	73%
7	15	3	18	83%
8	6	12	18	33%
9	7	8	15	47%
10	24	28	52	46%
11	13	12	25	52%
12	24	75	99	24%
13	14	21	35	40%
14	1	14	15	7%
15	3	12	15	20%
16	11	4	15	73%
Total	151	249	400	38%

In the Phase Three results of the previous study, BSG found significant non-compliance with the mandatory measures relating to hot water pipe insulation and fluorescent lighting requirements in the kitchen and bathrooms. The Post Occupancy Residential Survey found higher non-compliance rates with these measures. For the hot water pipe insulation, BSG reported an overall non-compliance rate of nearly 21 percent. NEOS found non-compliance rates were closer to 36 percent. BSG's findings with regard to the use of fluorescent fixtures in bathrooms showed a non-compliance of over 42 percent. This survey found non-compliance rates of over 75 percent. Finally, BSG documented non-compliance rates for the kitchen fluorescent lighting measure of just over 4 percent. The NEOS on-site survey found this level to be closer to 27 percent.

Removal Of Energy Efficiency Measures

Based on the data collected from the 400 houses included in this study, there were no significant levels of energy efficiency measure removal occurring in newly constructed houses in California. This included lighting measures, structural measures, window covering measures, landscaping measures, and water fixture measures. The removal of energy efficiency measures does not seem to be a major issue in the energy performance of newly constructed houses in California.

Addition Or Replacement Of Energy Efficiency Measures

This survey project determined that there is a significant amount of addition or replacement of energy efficient measures. Areas where considerable activity is taking place includes:

- Window coverings
- Shade trees
- Outdoor fixtures
- Faucets or showerhead replacement
- Incandescent lamp changeouts
- Fluorescent fixtures addition
- Replacement of worn or defective weather-stripping/caulking.

As expected, most homeowners do add window coverings and shade trees to their houses after they move into the house. The addition of these measures are more likely due to aesthetic reasons than for energy efficiency, but the end result is still higher energy efficiency.

A majority of new homeowners added landscaping or security lighting. These lights are not taken into consideration in the energy compliance requirements, but addition of outdoor lighting does increase energy use in the home.

This project uncovered a significant amount of replacement of showerheads and faucets. In some cases, this replacement was due to breakage or failure, but there were homeowners that had replaced showerheads and faucets to increase water flow. These replacements would tend to increase hot water usage and overall water use, which reduces the anticipated savings from these measures.

Approximately 10 percent of the homeowners surveyed had replaced incandescent lamps with compact fluorescent lamps. The vast majority of these had carried out such replacements in order to lower their utility bills and not because of utility rebates or other incentives. While not included in the original energy compliance measures for the home, use of these compact fluorescent lamps will reduce the energy use in the house, and indicates a market transformation effect for this technology.

When applicable, homeowners are adding fluorescent fixtures or replacing incandescent fixtures with fluorescent fixtures. While adding fixtures does not help reduce energy use in a house, replacing existing incandescent fixtures with fluorescent fixtures will reduce energy use. Although these items are not dealt with in the compliance code, these actions do effect the energy use at the house.

A significant portion of the homeowners had replaced weather-stripping and caulking to keep their houses from being drafty. Since the actions of the homeowner really keep the house to the original as-built condition, these actions have no impact on the Title 24 compliance. These actions do help to maintain the savings from these efficiency measures in new homes.

Sources Of Information For Homeowner Removal Or Installation

In reviewing the sources of information relied upon by the homeowner to make energy related decisions, past experience appears to be the main resource and reason for the homeowner in this decision making process. For certain measures, an interior decorator or a contractor may be consulted, and for certain equipment purchases, consumer guides were also mentioned. However, the primary source is predominantly past experience.

The reasons for making a change in a house were also strongly based on past experience, except in cases where equipment malfunctions required replacement of the appliance or the equipment in question. Past experience was nearly always indicated as the guide for an energy efficiency related action. This included everything from shade trees to window coverings to faucet replacements.

3.0 COMPARISON OF RESULTS BY CLIMATE ZONE

As evident from the previous section, each of the residential projects included in this comparison involved a different objective and, therefore, a different paradigm for the data collection and analysis process. For the Post Occupancy Residential project, a significant level of detail was gathered on housing and equipment characteristics and occupant behavior using one standard and consistent process of data collection throughout the project. On the other hand, no metering or monitoring activities were carried out, nor were utility bills gathered and analyzed. Therefore, in order to establish valid comparisons between the results from this project and those of the previous studies it was necessary to first define the proper cross-section of information common to all projects. As a result, of this effort, and from discussions with Commission staff, the following conclusions were drawn:

- Valid comparisons were best made between the on-site components of the data collection efforts which occurred in all projects. These elements of the data and the results provided the best common ground and match from which to conduct comparison analyses.
- Comparison of Statewide results was not considered feasible, since the current Post Occupancy Residential project was the only study which included data from all climate zones included in the Building Standards. Although the previous studies did contain statewide results, these were based on extrapolations of the data for only a subset of the climate zones.

Table 3-1 lists the number of on-site surveys in each of the three Commission residential compliance projects. Three different efforts were conducted in the 1990 project including a mail survey with 2,845 respondents, an on-site survey of 299 houses, and a metering study of 40 houses. The 1993 project (report in 1995) consisted of two data collection efforts including a gathering and review of 1,230 CF-1R compliance forms, and an on-site survey of 96 houses. The current NEOS project represents the largest on-site data collection effort with 400 houses and the widest geographic coverage with each of the sixteen climate zones having at least 15 on-site surveys. To facilitate comparisons of like data, the NEOS data separated based on the date of construction. The 354 houses built prior to 1994 were assumed to be built according to the 1988 Title 24 energy codes. Conversely, the remaining 46 homes built in 1994 and 1995 were assumed to be built in accordance with the 1992 Title 24 energy codes. Since the sample of the these 1992 Standard houses was small and divided among the climate zones, these houses were not used in the following comparisons.

Table 3-1 Number Of On-Site Participants By Residential Survey Project

Climate Zone	Xenergy On-Site Survey (1990) Built in 1984-88	BSG On-Site Survey (1993) Built in 1993-94	NEOS On-Site Survey (1996) Built in 1989-93	NEOS On-Site Survey (1996) Built in 1994-95
1			11	4
2	27		15	0
3	49		18	0
4	13		15	0
5			14	1
6			10	5
7	35		15	3
8			18	0
9	4		12	3
10	60	26	44	8
11	18		22	3
12	67	24	92	7
13	7	22	25	10
14	13	24	15	0
15			15	0
16	6		13	2
Statewide	299	96	354	46

Within each of the on-site surveys themselves, comparisons are also limited to the same data or type of information common between projects. Despite these limitations, a significant number of comparisons were possible between the information from the various projects. These comparisons are divided into four main categories of building characteristics, which are discussed in further detail below.

3.1 Building Structure

Data was available to make structural comparisons between the three projects on a number of building structural characteristics. These included 1) the number of floors 2) average floor area 3) ceiling insulation levels 4) floor type 5) floor insulation 6) type of window glazing 7) wall insulation 8) window area per floor area 9) window area.

There appeared to be little difference among the houses from the three projects in terms of number of floors, average floor area, floor type, window area per floor area, and average window area per household. Houses built since 1989, however, appear to have higher levels of roof, wall and floor insulation as well as more efficient window glazing, which is expected as the Standards become the construction norm.

3.1.1 Number Of Floors

In addition to the current study, data on the number of floors per household was only available from the homes participating in the 1993 on-site survey. Table 3-2 provides the detail of these comparisons and results where they could be made. At the climate zone level, there was very little variation between the two surveys and would indicate that the homes surveyed in the two projects have nearly identical characteristics for this variable.

Table 3-2 Average Number Of Floors Per Household

	1996 On-Site (Built in 1989-93)		**1993 On-Site (Built in 1993-94)**	
Climate Zone	**Total Number**	**Average # of Stories**	**Total Number**	**Average # of Stories**
10	44	1.7	25	1.7
12	92	1.6	23	1.5
13	25	1.4	22	1.1
14	15	1.5	24	1.3

3.1.2 Conditioned Floor Area

Table 3-3 identifies the average conditioned floor area per household as found in the three projects. In general, by climate zone, the average floor areas are within 500 square feet and in most cases are even closer. Between the three surveys, the average floor areas in the 1996 survey were larger than the 1990 survey, but in two of the climate zones, the average floor areas were larger in the 1993 survey than in the 1996 survey. In general, the average floor area appears to be increasing over time.

Table 3-3 Average Floor Area Per Household

Climate Zone	1990 On-Site (Built in 1984-88) No. of Sites	1990 On-Site (Built in 1984-88) Average Floorspace	1996 On-Site (Built in 1989-93) No. of Sites	1996 On-Site (Built in 1989-93) Average Floorspace	1993 On-Site (Built in 1993-94) No. of Sites	1993 On-Site (Built in 1993-94) Average Floorspace
2	27	2,068	15	2,188		
3	49	2,121	18	2,543		
4	13	2,465	15	2,149		
7	35	1,861	15	2,299		
10	57	1,725	44	1,985	25	2,405
11	18	1,903	22	1,940		
12	65	1,844	92	2,152	23	1,988
13	7	1,655	25	2,098	22	1,573
14	11	1,583	15	1,737	24	1,930

3.1.3 Ceiling Insulation Level

Table 3-4 identifies average ceiling insulation levels from the three on-site surveys. Average ceiling insulation levels were lowest in the 1990 on-site survey and are higher in the homes built since 1989. These overall ceiling insulation level increases indicate that the more restrictive 1988 Commission Standards were effective in improving insulation levels in homes across all climate zones compared from these studies.

Table 3-4 Average Ceiling Insulation Level Per Household

	1990 On-Site (Built in 1984-88)		1996 On-Site (Built in 1989-93)		1993 On-Site (Built in 1993-94)	
Climate Zone	**No. of Sites**	**Average R-Value**	**No. of Sites**	**Average R-Value**	**No. of Sites**	**Average R-Value**
2	23	28.9	15	31.6		
3	40	26.2	18	29.7		
4	7	23.4	15	33.3		
7	34	20.8	15	32.7		
10	60	24.9	44	30.6	25	29.4
11	16	29.0	22	35.5		
12	50	29.9	92	33.8	19	31.8
13	3	29.1	25	32.5	21	30.8
14	13	29.6	15	33.7	24	32.0

3.1.4 Floor Type

As identified in Table 3-5, the predominant floor type in the 1993 and 1996 surveys was concrete slab for Climate Zones 10, 12, 13 and 14. (No comparable data was available from the 1990 on-site survey.) The variations in predominate floor type are minimal and would indicate little or no change in this characteristic over the past decade.

Table 3-5 Predominant Floor Type Per Household

Climate Zone	1996 On-Site (Built in 1989-93)				1993 On-Site (Built in 1993-94)			
	No. Of Sites	Concrete Slab (%)	Vented Crawl Space (%)	Garage/ Unheated Basement (%)	No. Of Sites	Concrete Slab (%)	Vented Crawl Space (%)	Garage/ Unheated Basement (%)
10	44	97.7%	2.3%	0.0%	25	92.0%	8.0%	0.0%
12	92	85.9%	11.9%	2.2%	23	87.0%	13.0%	0.0%
13	25	100.0%	0.0%	0.0%	22	100.0%	0.0%	0.0%
14	15	100.0%	0.0%	0.0%	24	91.7%	8.3%	0.0%

3.1.5 Floor Insulation

Floor insulation information was not collected in a comparable format in the 1990 On-Site Survey. Comparable numbers were collected in the 1993 and 1996 surveys, but the number of houses in each climate zone with floor insulation were four or less in the 1993 survey and do not provide enough houses for a valid comparison with the 1996 survey. Overall, the 1993 survey showed average floor insulation levels of R-11. The 1996 survey, on the other hand, documented average floor insulation levels of at least R-19.

3.1.6 Glazing Type

No glazing type information was available from the 1990 and 1993 on-site data and reports. The 1996 on-site survey found that double glazing was by far the predominant window type in all homes (95.5 percent) and in all climate zones. Climate Zones 6, 8, and 9 showed higher than 10 percent levels of single glazed windows, however, even in these mild climate zones over 60 percent of the windows were still double glazed.

3.1.7 Wall Insulation

The wall insulation levels were reported in the 1990, 1993, and 1996 on-site surveys in ways that make comparison very difficult. While the 1996 on-site survey documented this data as distinct R-values, the 1990 and 1993 on-site surveys used ranges to report the findings. Because this approach was used, direct data comparisons can not be shown here. But upon review of the two different types of data, the average wall insulation levels seemed to have increased over time through the three on-site surveys. The wall insulation levels in the 1990 survey were predominately (82 percent) R-11. The 1996 survey found average wall insulation levels of at least R-12.8. The 1993 survey found the R-13 wall insulation was the most frequent insulation level. This would be expected as the Commission Standards have become the construction norm.

3.1.8 Window Area Per Floor Area

Window area, expressed as a percent of floor area, is identified in Table 3-6. Review of the values from all three projects by climate zone indicates that the average window area per floor area is increasing over time. While not definitive, the general trend of window area per floor area seems to indicate that more window area is included in the design and construction of newer homes. This can have an impact on the energy use of newly constructed houses and may require adjustments in the estimations of window area per floor area in the various climate zones, and in the typical residence characteristics used in the energy analysis to develop the Standards.

Table 3-6 Average Window Area Per Floor Area

	1990 On-Site (Built in 1984-88)		1996 On-Site (Built in 1989-93)		1993 On-Site (Built in 1993-94)	
Climate Zone	No. Of Sites	Average Percentage	No. Of Sites	Average Percentage	No. Of Sites	Average Percentage
2	27	13.3%	15	16.5%		
3	49	14.7%	18	16.9%		
4	12	14.6%	15	19.6%		
7	35	17.1%	15	16.0%		
10	57	15.2%	44	16.9%	25	18%
11	18	14.9%	22	14.7%		
12	64	13.7%	92	17.3%	23	17%
13	7	11.9%	25	14.7%	22	14%
14	11	14.9%	15	19.4%	24	16%

3.1.9 Average Window Area Per Household

As indicated in the previous section, the window area per floor area ratios show an increasing trend over time. The data presented in Table 3-7 further reinforces this trend. With a few exceptions, the historic trend presented in Table 3-7 shows the average window square footage per house is lowest in the 1990 survey and increased in the 1996 and 1993 surveys. Once again, this trend provides an indication that the average amount of window area per home has been increasing over time.

Table 3-7 Average Window Area Per Household

	1990 On-Site (Built in 1984-88)		1996 On-Site (Built in 1989-93)		1993 On-Site (Built in 1993-94)	
Climate Zone	**No. Of Sites**	**Average (SqFt)**	**No. Of Sites**	**Average (SqFt)**	**No. Of Sites**	**Average (SqFt)**
2	27	279	15	366		
3	49	309	18	430		
4	13	352	15	413		
7	35	320	15	367		
10	57	259	44	342	25	434
11	18	293	22	287		
12	65	253	92	373	23	332
13	7	205	25	307	22	214
14	11	255	15	330	24	309

3.2 HVAC Equipment

Comparisons between the HVAC equipment data between the three projects were carried out on four variables. These are: 1) cooling equipment efficiency (SEER), 2) cooling equipment types, 3) heating equipment efficiency (AFUE), and 4) heating fuel type. Each of these variables is discussed below.

3.2.1 Cooling Equipment Efficiency (SEER)

Table 3-8 identifies the average cooling equipment efficiencies (SEER) found in the houses participating in the three projects. Although the data from the 1990 survey was not complete and the sample sizes are small, based on the available information, the average SEER shows an increase over time. No significant differences in the SEER are evident between the 1993 project and the current project, but it does appear that the cooling equipment efficiencies were significantly lower in the 1990 study. Once again, these increases in efficiency can be attributed to improvements in technology, greater availability of high efficiency cooling equipment, and the increased cooling energy efficiency requirements of the Standards. The current Standards require a SEER of 10.0 for split system air-conditioners.

Table 3-8 Average Cooling Equipment Efficiency (SEER)

	1990 On-Site (Built in 1984-88)		1996 On-Site (Built in 1989-93)		1993 On-Site (Built in 1993-94)	
Climate Zone	**No. Of Sites**	**Average**	**No. Of Sites**	**Average**	**No. Of Sites**	**Average**
2	1	11.3	4	9.6		
3	6	8.7	12	10.1		
4	0	N/A	12	10.5		
7	5	9.1	5	10.0		
10	16	9.6	41	10.2	20	10.50
11	4	9.2	21	10.6		
12	12	9.3	80	10.1	21	11.31
13	0	N/A	16	11.1	18	11.43
14	2	8.6	11	10.8	19	10.31

3.2.2 Cooling Type

It was difficult to make direct comparisons among the three projects in terms of type of cooling equipment. Cooling equipment categories were somewhat different from project to project. The two most comparable cooling equipment data were from the 1993 project and the current project, although the categories were still not identical. Even though direct comparisons could not be made, a review of the various cooling categories showed that the predominant cooling equipment type for both the current and 1993 projects was the split system followed by the packaged system. In both projects, direct evaporative coolers represented a very small percentage of system types.

3.2.3 Heating Equipment Efficiency (AFUE)

Table 3-9 identifies the average heating equipment efficiencies (AFUE) as identified in the 1993 and in the current project. AFUE values were not provided in the 1990 on-site project. Comparison of the average values from the two projects shows minimal difference between them. For three of the four climate zones shown, the average AFUE is slightly smaller. Reviewing the magnitude of these changes makes it appear that the AFUE values from the current project and the 1993 project are essentially the same. Since the vintage of homes contained in the samples from the 1993 and 1996 study are also essentially the same, this result is expected. The current Standards require an AFUE of 78 percent for gas space heating systems.

Table 3-9 Average Heating Equipment Efficiency (AFUE)

	1996 On-Site (Built in 1989-93)		**1993 On-Site (Built in 1993-94)**	
Climate Zone	**No. Of Sites**	**AFUE Average**	**No. Of Sites**	**AFUE Average**
10	25	77.8%	21	80.3%
12	64	77.8%	19	82.8%
13	15	78.8%	19	79.6%
14	7	81.7%	19	80.1%

3.2.4 Heating Fuel Type

Comparisons of space heating fuel types were available for all three on-site data collection efforts. Table 3-10 lists the percentages by space heating fuel type from all three projects. In the current project, natural gas is the only fuel type in each climate zone. The 1993 survey also shows natural gas is exclusively used in three of the climate zones, while some propane is used in Climate Zone 10. The 1990 survey shows a greater use of other fuels, such as propane, electricity, wood, solar, and other. This data may show an indication toward a greater use of natural gas over other fuels, but this heating fuel type data is more likely driven by the locations selected for the sample size. For example, the use of propane may not indicate a preference for propane, but a lack of availability of natural gas. This is especially true in the more remote areas, which have no natural gas service.

3.3 Hot Water Equipment

Comparisons between the projects for water heating equipment were made for water heater efficiencies and water heater fuel type. These comparisons could only be made, however, between the current project and the 1990 project for water heater efficiency, because no recovery efficiency (RE) was collected in the 1993 study. Likewise fuel type comparisons could only be made with the 1993 data, since the 1990 data were not segmented in a comparable manner.

Table 3-10 Percentage Of Heating Fuel Types

Climate Zone	1990 On-Site (Built in 1984-88) No. Of Sites	Natural Gas	Propane	Electricity	Other	Wood	Solar	1996 On-Site (Built in 1989-93) No. Of Sites	Natural Gas	1993 On-Site (Built in 1993-94) No. Of Sites	Natural Gas	Propane
2	26	53.8%	3.8%	7.7%	26.9%	7.7%	0.0%	15	100.0%			
3	49	89.8%	0.0%	4.1%	6.1%	0.0%	0.0%	18	100.0%			
4	12	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15	100.0%			
7	34	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15	100.0%			
10	59	86.4%	5.1%	3.4%	3.4%	0.0%	1.7%	44	100.0%	25	96.0%	4.0%
11	18	50.0%	11.1%	11.1%	16.7%	11.1%	0.0%	22	100.0%			
12	64	81.3%	3.1%	3.1%	3.1%	9.4%	0.0%	92	100.0%	23	100.0%	0.0%
13	6	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25	100.0%	22	100.0%	0.0%
14	13	69.2%	23.1%	0.0%	0.0%	0.0%	7.7%	15	100.0%	24	100.0%	0.0%

3.3.1 Water Heater Efficiency

Table 3-11 identifies the water heater efficiency values between the 1990 and current project. As evident, the average water heater efficiencies from both projects are nearly identical. The current project has average water heater recovery efficiencies (RE) ranging from 75 percent to 78 percent by climate zone compared to the 1990 on-site houses with RE values of approximately 76 percent. It can be concluded that the water heater efficiencies of the houses in these two projects are essentially the same.

Table 3-11 Average Water Heater Efficiency (RE)

	1990 On-Site (Built in 1984-88)		1996 On-Site (Built in 1989-93)	
Climate Zone	**No. Of Sites**	**Average**	**No. Of Sites**	**Average**
2	17	76.1%	15	75.0%
3	31	76.3%	7	77.0%
4	6	76.0%	15	78.0%
7	26	76.1%	15	76.0%
10	42	76.1%	41	78.0%
11	7	76.0%	19	77.0%
12	39	76.1%	74	77.0%
13	6	76.0%	22	78.0%
14	9	76.5%	11	78.0%

3.3.2 Water Heater Fuel Type

Comparisons of water heater fuel type are limited to the current project and the 1993 project. Table 3-12 identifies these fuel types and shows that the data follows a similar pattern as that found with the space heating fuel type. In the current project, natural gas is the predominant water heater fuel type in all climate zones. Only one house in climate zone 12 had a water heater fuel other than natural gas in the current study.

The water heater fuel type in the 1993 on-site survey houses was also predominantly natural gas, except in Climate Zone 10 and 14. As with the space heating fuel, this data may show an indication toward a greater use of natural gas over other fuels. The choice of water heating fuel type is also likely driven by the locations selected in the sample. For example, the use of propane may not indicate a preference for propane, but a lack of availability of natural gas. This is especially true in the more remote areas, which have no natural gas service.

Table 3-12 Percentage Of Water Heating Fuel Types

Climate Zone	1996 On-Site (Built in 1989-93) No. Of Sites	Natural Gas	Electricity	Solar w/ Natural Gas	1993 On-Site (Built in 1993-94) No. Of Sites	Natural Gas	Propane	Electricity
10	44	100.0%	0.0%	0.0%	25	44.0%	52.0%	4.0%
12	92	97.8%	1.1%	1.1%	33	95.7%	4.3%	0.0%
13	25	100.0%	0.0%	0.0%	22	95.5%	4.5%	0.0%
14	15	100.0%	0.0%	0.0%	26	50.0%	42.3%	7.7%

3.4 Appliances

Comparisons between the data from the various projects were made by looking at the presence of and/or fuel type of clothes washers and dryers, cooking (in general), freezers, and hot tubs/spas. In general, the presence of freezers was shown to be lower in the current project and 1993 projects than in comparison to the 1990 project. Natural gas is more common as the fuel for clothes drying and cooking in the current data than in the 1993 data. Some of these differences may be driven by fuel share differences by climate zone and the different distribution of sample points by climate zone between the two projects. The presence of hot tubs/spas appears to be lower in the current project compared to the 1990 project; however, the number of sample points for these appliances is also relatively small in the data from all projects.

3.4.1 Washer/Dryer

Table 3-13 lists the comparisons of the presence of washers/dryers in the houses participating in the current project, the 1993 project, and the 1990 project by climate zone where available. Virtually all of the houses in the current project had a washer and a dryer. The minimum share of washer/dryers in the 1993 survey was 95 percent, at the climate zone level, while at least 85 percent of the houses in the 1990 survey also had a washer and a dryer at the climate zone level.

Table 3-13 Average Presence Of Washers And Dryers

	1990 On-Site (Built in 1984-88)			1996 On-Site (Built in 1989-93)			1993 On-Site (Built in 1993-94)		
Climate Zone	No. Of Sites	Washer	Dryer	No. Of Sites	Washer	Dryer	No. Of Sites	Washer	Dryer
2	27	92.6%	92.6%	15	100.0%	100.0%			
3	49	95.9%	93.9%	18	100.0%	100.0%			
4	13	100.0%	100.0%	15	100.0%	100.0%			
7	35	97.1%	94.3%	14	100.0%	100.0%			
10	59	100.0%	98.3%	44	100.0%	100.0%	25	100.0%	100.0%
11	18	100.0%	100.0%	22	100.0%	100.0%			
12	67	100.0%	100.0%	92	100.0%	100.0%	23	95.7%	95.7%
13	7	85.7%	85.7%	25	100.0%	100.0%	22	95.5%	95.5%
14	13	100.0%	100.0%	15	100.0%	100.0%	24	100.0%	100.0%

Another interesting observation from the data is the strong correlation between the presence of both appliances in the home.

3.4.2 Clothes Dryer Fuel Type

Table 3-14 identifies the clothes dryer fuel type for the current project and the 1993 on-site survey. In the current project, the clothes dryer fuel shares for natural gas ranged from 29 percent to 84 percent by climate zone. The 1993 shares by climate zone ranged from 22 percent to 40 percent. It can be concluded that average clothes dryer fuel type is significantly different between the current project and the 1993 project. Some of these differences are driven by differences in the sample populations by climate zone, however, these results are also indicative of the increasing trend toward the use of natural gas as the fuel type of choice whenever possible.

Table 3-14 Percentage Of Dryer Fuel Types

Climate Zone	1996 On-Site (Built in 1989-93) No. Of Sites	Natural Gas	Electricity	1993 On-Site (Built in 1993-94) No. Of Sites	Natural Gas	Propane	Electricity
10	44	84.1%	15.9%	25	40.0%	28.0%	32.0%
12	92	29.3%	70.7%	23	21.7%	0.0%	78.3%
13	25	60.0%	40.0%	21	28.6%	0.0%	71.4%
14	15	80.0%	20.0%	23	34.8%	21.7%	43.5%

3.4.3 Cooking Fuel Type

Comparison data were available for the cooking fuel type from the 1993 and 1996 projects and are presented in Table 3-15. The cooking fuel type shares between the two projects are significantly different. The current project is dominated by natural gas as the cooking fuel with a fuel share of ranging from 63 percent to 100 percent depending on climate zone. In the 1993 project, natural gas was still the most common cooking fuel, but propane accounted for a significant portion of the fuel share. Since the sample from both projects represents similar vintages of houses, such variations can only be explained by differences in the sample population and location of the homes within each climate zone.

Table 3-15 Percentage Of Cooking Fuel Types

Climate Zone	1996 On-Site (Built in 1989-93) No. Of Sites	Natural Gas	Electricity	1993 On-Site (Built in 1993-94) No. Of Sites	Natural Gas	Propane	Electricity
10	52	100.0%	0.0%	25	40.0%	36.0%	24.0%
12	99	70.7%	29.3%	23	26.1%	4.3%	69.6%
13	35	62.9%	37.1%	21	31.8%	0.0%	68.2%
14	15	93.3%	6.7%	23	8.3%	41.7%	50.0%

3.4.4 Freezer

Table 3-16 lists the shares representing the presence of freezers in the houses participating in the current project, the 1993 survey and the 1990 survey. In all three projects, the presence of freezers was smaller than 40 percent, except for the 1990 data for Climate Zone 11.

Table 3-16 Average Presence Of Freezers

	1990 On-Site (Built in 1984-88)		1996 On-Site (Built in 1989-93)		1993 On-Site (Built in 1993-94)	
Climate Zone	**No. Of Sites**	**Average**	**No. Of Sites**	**Average**	**No. Of Sites**	**Average**
2	27	25.9%	15	13.3%		
3	49	20.4%	18	11.1%		
4	13	23.1%	15	20.0%		
7	35	20.0%	15	40.0%		
10	60	20.0%	44	25.0%	25	8.0%
11	18	55.6%	22	18.2%		
12	67	35.8%	92	23.9%	23	17.4%
13	7	14.3%	25	32.0%	22	9.1%
14	13	23.1%	15	33.3%	24	37.5%

3.4.5 Hot Tub/Spa

Table 3-17 shows a comparison of the average share of hot tubs/spas at the houses participating in the current project, the 1993 survey and the 1990 survey. The presence of hot tubs/spas varies greatly between the three projects with no real pattern. Each climate zone and survey indicated differing percentages. The presence of hot tubs/spas appears to be highly variable by climate zone ranging from a low of 0.0 percent to a high of 26.7 percent. Differences between the three projects in terms of the presence of hot tubs/spas is probably driven by the differences in sample population by climate zone, however, the data do also show that these appliances are present in a relatively small proportion of the homes. No correlation was possible between the presence of these appliances and household income over time, although the relationship can be expected to be statistically significant.

Table 3-17 Average Presence Of Hot Tub/Spa

	1990 On-Site (Built in 1984-88)		1996 On-Site (Built in 1989-93)		1993 On-Site (Built in 1993-94)	
Climate Zone	**No. Of Sites**	**Average**	**No. Of Sites**	**Average**	**No. Of Sites**	**Average**
2	27	7.4%	15	26.7%		
3	49	10.2%	18	11.1%		
4	13	7.7%	15	0.0%		
7	32	18.8%	15	6.7%		
10	60	25.0%	44	11.4%	25	16.0%
11	18	0.0%	22	0.0%		
12	66	12.1%	92	19.6%	23	0.0%
13	7	0.0%	25	0.0%	22	4.5%
14	11	0.0%	15	6.7%	24	8.3%

4.0 COMPARISON OF CALRES RESULTS

The CALRES program was used in this project and in two of the phases of the Residential Building Standards Monitoring Project. In Phase One of the previous project, CALRES simulations were made based upon on-site survey data and STEM monitoring data. In Phase Three of the previous project, CALRES simulations were made on houses using survey data and data from the CF-1R forms, when needed. In this project, NEOS conducted pre-occupancy and post-occupancy CALRES simulations based, exclusively, on the survey data.

The CALRES program was designed to provide computerized performance method simulation as a check for energy code compliance. CALRES calculates annual heating and cooling energy consumption for a typical weather year and domestic water heating energy consumption on an annual basis. The program is based on the existing modeling assumptions for building and thermal properties, many of which are fixed and cannot be modified by the user.

Although the CALRES program was used in two phases of the previous project and in this project, Phase One of the previous project did not provide enough detail in the project report information to facilitate comparison of the results at the climate zone level. Consequently, the analysis presented in this section is between the Phase Three data and the current project data only. For these comparisons, the pre-occupancy data were used, since that is the house condition intended to comply with the Title 24 energy codes. The CALRES simulations made with the Phase Three data were completed using CALRES2 or the 1992 Standards. CALRES simulations completed with the data from the current project were conducted based on the year of construction of the houses. CALRES or the 1988 Standards were used for 354 houses and CALRES2 or the 1992 Standards were used for the remaining 46 houses. Since the 46 houses were divided among the climate zones, which resulted in small sample sizes by climate zone, these houses were not included in the comparisons with the previous projects.

In the CALRES simulations documented for both the Phase Three of the Residential Building Standards Monitoring Project and the Post Occupancy Residential Survey Project, the percentage of homes which complied with the standards on a performance basis was significantly lower than 100 percent. There were several reasons for this. Most importantly, however, was the purpose of the simulations. When a home builder or designer is seeking compliance with the energy standards, every possible approach is examined and applied to help meet compliance with the Standards. If compliance with the Standards cannot be documented, the house cannot be built. Also, the compliance documentation can vary significantly from the house as it was finally built. Within these two projects, the Standards and CALRES simulations are applied dispassionately. All houses are modeled using the same approach to eliminate possible bias toward a climate zone, type of house, or other characteristics of the house. This provides for a more even handed approach to simulating these houses in comparison to the desire to have every home meet compliance with the Standards. Thus, no “fine-tuning” of the input data was utilized in either study to increase the compliance rate.

4.1 Performance Based Compliance

The first comparison of CALRES results relates to the determination of compliance to the Title 24 energy codes. In Table 4-1, compliance vs. non-compliance data is presented for the 1993 Phase Three project. This data uses the July 1993 requirements (or the stricter glazing U-factor test requirements). The houses in Climate Zone 10 showed the greatest level of compliance, while Climate Zone 14 showed the lowest level of compliance.

Table 4-1 Performance Compliance of As Built Audited Houses (Phase Three of the Residential Building Standards Monitoring Project)

Climate Zone	Comply	Don't Comply	Total	% Complying
10	18	8	26	69%
12	7	17	24	29%
13	11	11	22	50%
14	2	22	24	8%
Total	38	58	96	40%

Table 4-2 displays, the compliance vs. non-compliance data for the 1996 Post Occupancy Residential Survey houses built between 1989 and 1994. While individual houses showed compliance in each climate zone, the lowest percentages of compliance were in Climate Zones 12 and 14. This mirrors the results from Phase Three of the Residential Building Standards Monitoring Project. A higher percentage of the homes showed compliance in Climate Zone 10 and 13, but not as high as in the previous project.

Table 4-2 Performance Compliance of As Built Audited Houses (Post Occupancy Residential Survey Project)

Climate Zone	Comply	Don't Comply	Total	% Complying
10	17	27	44	39%
12	24	68	92	26%
13	12	13	25	48%
14	1	14	15	7%
Total	54	122	176	31%

Care should be exercised in the comparison of the percentages shown for the total cross-section of the sample between the two studies. The sample sizes are not identical in each of the climate zones, which skews the total. This illustrates why it is important to examine the results of the comparisons at the climate zone level and avoid generalized statewide comparisons of the data between the projects.

The comparisons of the results at the climate zone level represent the important observation to be made here. Both studies showed similar patterns of compliance in the results at that level. In Section Three, comparisons were made, by climate zone, between the average data collected in the Phase Three project and the current Post Occupancy project. These comparisons showed differences in house size, window area to floor area percentage, and heating and cooling equipment efficiencies. These differences, while in some cases improving house energy efficiency and in other cases reducing house energy efficiency, provide the basis for the different levels of compliance by climate zone for each of the two projects.

While the levels of compliance are not identical between these two projects, this comparison does show consistency by climate zone. Both projects showed lowest levels of compliance occurred in Climate Zone 14 and the highest levels of compliance occurred in Climate Zone 10. These results may indicate a higher degree of difficulty in meeting compliance in Climate Zone 12 and 14. A comparison of the average percentage margin of compliance between these two projects show the compliance margins were within four percentage points in Climate Zones 10, 12, and 13. This indicates that, on an average, the simulation results were comparable between the two projects. The lone exception is Climate Zone 14, which had similar results, but a greater magnitude of difference, which may be related to the small sample size for this climate zone in the “Post Occupancy Survey Project.”

4.2 CALRES Results

The second comparison of CALRES results relates to the average energy use for all of the houses in a particular climate zone in relation to the expected value from the Standard. The difference between these values is defined as the percent margin. Positive values in the percent margin indicate that the homes perform better than the expected Standard, while negative values show that, on average, the level of energy use in these homes is more than the expected value. In Table 4-3, as built vs. standard design data are presented for the 1993 Phase Three project. As before, this data uses the July 1993 requirements (or the stricter glazing U-factor test requirements). The houses in Climate Zone 10 showed the greatest level of compliance, while Climate Zone 14 showed the lowest level of compliance.

Table 4-3 Average Energy Performance of As Built Audited Houses (Phase Three of the Residential Building Standards Monitoring Project)

Climate Zone	As Built (kBtu/sf-yr)	Standard (kBtu/sf-yr)	% Margin	Total
10	32.7	33.8	3%	26
12	35.2	33.1	-6%	24
13	39.0	38.4	-1%	22
14	43.8	40.4	-8%	24

Table 4-4 displays the pre-occupancy (or as built) vs. standard design data for the Post Occupancy Residential survey for the houses built between 1989 and 1994. In reviewing this data, Climate Zone 14 showed the lowest average compliance margin. Conversely, Climate Zone 10 displayed an energy use level close to the standard design.

Table 4-4 Average Energy Performance of As Built Audited Houses (Post Occupancy Residential Survey Project)

Climate Zone	As Built (kBtu/sf-yr)	Standard (kBtu/sf-yr)	% Margin	Total
10	42.14	41.62	-1%	44
12	49.86	46.94	-6%	92
13	53.24	51.71	-3%	25
14	78.36	67.62	-16%	15

In comparing the percentage margin between the two projects, Phase, the margins are within four percentage points in Climate Zones 10, 12, and 13. This again indicates that, on an average, the simulation results are comparable between the two projects. The lone exception is Climate Zone 14, which had similar results, but a greater magnitude of difference. Once again, this may be an indication that differences in house size, window area to floor area percentage, and heating and cooling equipment efficiencies affect the results of the two projects. In Climate Zone 14, the size of the sample, or number of houses, may also have had an impact on the average percentage margin. If fewer houses are simulated, their results could more easily skew the average value for the climate zone. In other words, the climate zones with the larger number of houses surveyed provide more confidence in the results.

5.0 SUMMARY AND CONCLUSIONS

After comparing the data and results from the two reports generated for the “Residential Building Standards Monitoring Project”, *Occupancy Patterns & Energy Consumption in New California Houses* and *Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses*, with the data and results from the “Post Occupancy Residential Survey Project”, overall conclusions can be drawn in three major areas. First, since these projects collected data on newly constructed homes over an eight year period, conclusions could be made regarding the changes in building insulation levels and equipment efficiency over time. Second, levels of compliance with the Title 24 energy standards were compared and contrasted on a climate zone level. Finally, like data elements from the two reports and the current project were analyzed to determine if the homes surveyed in these projects showed enough similarity to provide credence to the results documented in the “Post Occupancy Residential Survey Project” final report.

Since the data collected from these projects were collected on homes that were built at different points in time, the data should show improvements in energy efficiency and technology as newer homes are compared to homes built under previous energy standards. This is expected because the Standards have become more stringent and the energy efficiency of equipment has improved. This assumption was verified by the data. The two data collection efforts which covered the same time period, Phase Three of the “Residential Building Standards Monitoring Project” and the “Post Occupancy Residential Survey Project” had higher ceiling, wall, and floor insulation levels and more efficient window glazing than data collected on homes built from 1984 through 1988 (Phase One). Similarly, improvements in the efficiencies of HVAC equipment are shown through comparison of the three projects. There appeared to be little difference between the HVAC equipment in the “Post Occupancy Residential Survey Project” and the houses that participated in the 1993 project (Phase Three). Differences do appear between the Phase One project houses. In the more recent projects, the cooling equipment SEER and heating equipment AFUE appear to be higher, which is expected based on differences in year of construction for the houses. Historic comparisons on the efficiency of the hot water equipment were not made, since efficiencies in the Phase One data were collected using Recovery Efficiencies and the “Post Occupancy Residential Survey Project” collected the efficiency data using Energy Factors.

Comparisons of compliance with energy codes were made using the CALRES simulation model. These comparisons were between simulations made on the houses surveyed in Phase Three of the “Residential Building Standards Monitoring Project” and the houses surveyed in the “Post Occupancy Residential Survey Project”. While the levels of compliance were not identical between these two projects, the comparisons did show consistency by climate zone. Both projects showed the lowest levels of compliance occurred in Climate Zone 14 and the highest levels of compliance occurred in Climate Zone 10. These results may show a climate zone bias in the Standards or a need for a greater level of energy standard enforcement Climate Zones 12 and 14. A comparison of the average percentage margin of compliance between these two projects show the compliance margins were within four percentage points in Climate Zones 10, 12, and 13. This indicates that, on an average, the simulation results were comparable between the two projects. The lone exception is Climate Zone 14, which had similar results, but a greater magnitude of difference, which may be related to the small sample size for this climate zone in the "Post Occupancy Residential Survey Project."

Finally, comparisons were made on a wide range of data elements between the three on-site survey projects. While these data elements were not expected to show variance based on the year of construction or are important energy standard compliance variables, they do show an indication of the similarity in the type and characteristics of the houses that were surveyed. In the area of building structure, there appeared to be little difference among the houses from the three projects in terms of number of floors, average floor area, or floor type, For home appliance information, comparisons between the projects were made by looking at the presence and in some case fuel type of clothes washers and dryers, cooking equipment, freezers, and hot tub/spa. The only major differences between the three on-site surveys is that the presence of freezers was lower in the "Post Occupancy Residential Survey Project" when compared to the Phase One data collection. Also, natural gas was used more commonly as the fuel for clothes drying and cooking with the "Post Occupancy Residential Survey Project" than the two previous projects and the presence of hot tubs/spas appears to be lower in the current project compared to the 1990 project. These small differences are most likely based on the sample selection rather than any true differences in the homes surveyed for these projects. In general, the characteristics of the homes surveyed in these three on-site surveys are very similar and show no major differences which would discourage use of the "Post Occupancy Residential Survey Project" data from all the climate zones in further research and analyses.

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